
BEACH DEPOSITS OF ILMENITE, ZIRCON AND RUTILE
IN FLORIDA

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BEACH DEPOSITS OF ILMENITE, ZIRCON AND RUTILE IN FLORIDA

JAMES H. C. MARTENS

INTRODUCTION

Deposits of ilmenite, zircon, and rutile on the ocean beach of the East Coast of Florida between St. Johns River and St. Augustine Inlet, which are unlike any worked elsewhere in the United States, account for most of the domestic production of these three minerals. All of these minerals are common and normal constituents of sands, but ordinarily they are in such small amount that they are of no value.

The workable deposits in Florida are due to the action of the waves in concentrating the small grains scattered through the sand. Not only these three minerals, but numerous others heavier than ordinary quartz sand, are mixed together in the concentrate formed by the waves, and we may therefore speak of the ore as a "heavy concentrate." Since ilmenite, the most abundant of these minerals, is black, sand containing it in sufficient amount may be briefly described as "black sand" without, however, implying that it is the only cause of black color in sands.

The origin of the deposits will be discussed rather fully because it is closely related to their mode of occurrence and distribution. As will be explained later on, not only is there nothing mysterious about these deposits, but rather the wonder might be that deposits large enough to be workable are not more common. Other important topics to be considered are the methods used in the separation of the minerals in the very complex natural concentrate, and the development of uses for the elements zirconium and titanium and their compounds. The detailed discussion which follows refers principally to the deposit near Mineral City. Other localities (see Figure 26) are referred to much more briefly.

D. M. Liddell¹ has given a brief account of the occurrence of ilmenite, zircon, rutile, and monazite near Mineral City, and the early stages of mining there, but he greatly overestimated the extent of the workable deposit.

The writer wishes to thank Mr. W. M. Phillips of Buckman and Pritchard, Inc., for his courtesy in freely giving information about the plant and the deposits, without which it would have been impossible to prepare this paper.

DISCOVERY AND DEVELOPMENT

H. H. Buckman and G. A. Pritchard first noticed the occurrence of ilmenite in commercial quantities on the beach near where Mineral City now is and began production of ilmenite in 1916. They are said to have examined the coast from near Charleston, S. C., to the Straits of Florida, a stretch of more than 800 miles; also both banks of Indian River, and a part of the Gulf Coast of Florida, but decided that the only place where ilmenite was found in commercial quantities was between St. Johns River and St. Augustine.

The first mining development was for war purposes, to supply titanium minerals for the manufacture of titanium tetrachloride, a fuming liquid which was used in tracer bullets, spotting shells and gas offense. For a while only the ilmenite was recovered from the sand, but as new uses became known for rutile and zircon, means were devised for separating them also from the sand, and when the best deposits conveniently near the mill became depleted, the tailings heaps from the earlier operations were worked over.

The mining and milling operations at Mineral City are still under the name of Buckman and Pritchard, Inc., which is now a subsidiary of the National Lead Company.

¹A Florida Rare-Mineral Deposit. Engineering and Mining Journal, vol. 104, pp. 153-155; 1917.



FIG. 26. Map of part of the southeastern states, showing boundary between Piedmont Plateau and Coastal Plain and localities of ilmenite concentrates.

DEPOSITS NEAR MINERAL CITY

STRUCTURE AND EXTENT

From the mouth of the St. Johns River to St. Augustine Inlet, a distance of 35 miles, the ocean beach (Figure 27) is nearly straight and is rather uniform in its topographic features. The position of Mineral City, near which the deposits were originally richest, and where the mill of Buckman and Pritchard, Inc., is located, is shown on the map (Figure 26). The width of the beach for most of this distance is about 500 feet at low tide. At the back of the beach is a line of dunes usually a few hundred feet wide and varying in height up to 30 feet or a little more. A large part of the way along the beach there is a distinct wave cut cliff or notch in the dune front, which has been produced during storms, since it is not reached at high tide in calm weather. For many miles inland none of the land is as high as the highest dunes, and from Mineral City southward to St. Augustine Inlet, there are marshes immediately in back of the dunes.

The heavy concentrate or ore always occurs in beds, which may best be described as "strips" since the bodies are much wider than they are thick, and much longer than they are wide, the direction of greatest extent being parallel to the shore. The principal beds occur on the back part of the beach at the foot of the dunes and extending out a short distance in front of them (Figure 28). The ore is in the form of a fine sand, even finer than the ordinary beach sand, and is easily recognized by its dark



FIG. 27. General view of beach near Mineral City, St. Johns County.

color and heavy weight. A cut through the back part of the beach will usually reveal a succession of thin light and dark beds, the dark ones varying in thickness from a small fraction of an inch up to about six inches, while the light ones are generally thicker. As shown in Figure 29, there is frequently a fairly thick layer of black sand almost immediately below the surface, while deeper down there is a succession of thinner layers of light and dark.

During the early period of working the richest streak of black at the foot of the dunes contained 60 per cent of "mineral," (heavy minerals recovered in the wet mill) for a thickness of 2 to 2½ feet and a width of 25 to 35 feet, but the average of the sand as worked has recently been around

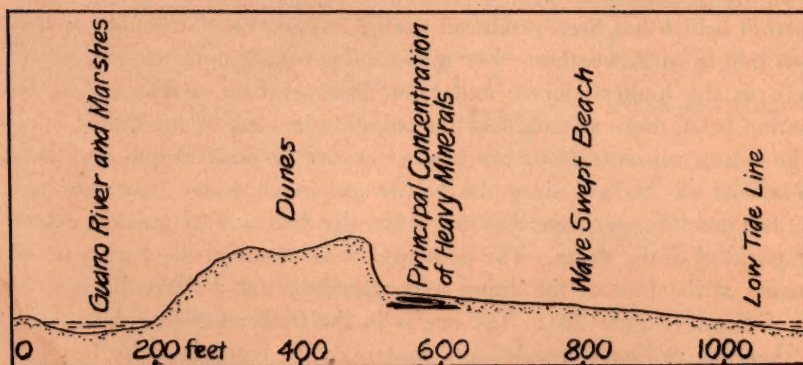


FIG. 28. Generalized section of beach south of Mineral City, St. Johns County. Vertical scale greatly exaggerated.

20 per cent "mineral" and the dimensions as worked somewhat smaller. Samples can be obtained which are practically free from quartz and therefore may be said to contain 100 per cent "mineral," but such material is in too thin layers to select it in mining so a certain amount of the quartz sand has to be mined also. All of the dunes and beach sand contains some of the ilmenite and associated minerals, so that there is not always a sharp distinction between material that is workable and that which is not. Beside the beds on the back part of the beach, some of the adjoining part of the dunes selected as appearing richest in dark minerals, has also been worked.

The workings have extended three miles north of the mill at Mineral City, and eight miles south. To the north the deposits continue somewhat farther but the beach is developed as a pleasure resort to such an extent as to prevent mining operations. Farther to the south the heavy concentrate

probably is of workable grade and depth for several miles, and is likely to be mined when a road is built so as to make it more easily accessible.

MINERAL COMPOSITION.

Both the heavy concentrates and the associated beach and dune sand are entirely loose and unconsolidated and of very fine texture. The sand of the lake beaches is generally coarser than that of the ocean beach.

The same heavy minerals are present in the ordinary beach and dune sand as in the heavy concentrate, but in much smaller amount. There are all gradations from the dark heavy concentrates with only a few per cent

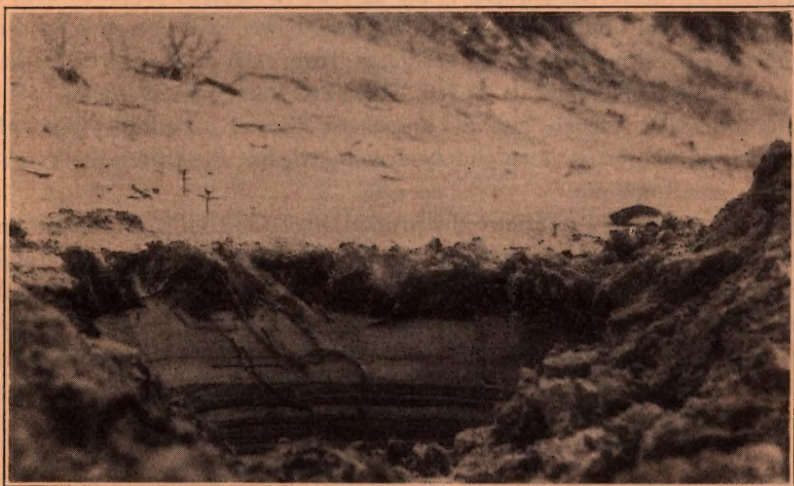


FIG. 29. Alternating layers of heavy concentrates and quartz sand at back of beach near Mineral City, St. Johns County.

of quartz to sand which is practically all quartz with only scattered grains of the heavy minerals. What constitutes workable material or ore will therefore depend upon the price of the product, the efficiency of the methods used in separating the minerals from the sand, and the size of the deposit and its situation.

Microscopic examination is the only practicable method of determining the mineral composition since there is too complicated a mixture for chemical analysis to be of much help, and anything approaching complete separation of the minerals by mechanical means is excessively difficult.

Using both a petrographic microscope and a binocular, the writer found and identified the following minerals in sand from the strip of beach between St. Johns River and St. Augustine:

Quartz	Epidote	Tourmaline	Calcite (shell)
Ilmenite	Zoisite	Hornblende	Feldspar
Zircon	Garnet	Leucoxene	Muscovite
Rutile	Disthene	Collophane	Biotite
Monazite	Sillimanite	Spinel	Graphite
Staurolite	Magnetite	Anatase	Corundum

Pyroxene, pyrochlore, and xenotime are reported as among the minerals found here by D. H. Newland, but they were not seen by the writer, and must be very scarce. Andalusite is the only other mineral found in heavy concentrates from other parts of Florida, which was not also seen in the specimens from Mineral City. In specimens from each of the eleven localities represented the minerals quartz, ilmenite, staurolite, disthene, sillimanite, tourmaline, leucoxene, and spinel are present. Perhaps a few of the other minerals may be as widely distributed, but if so they are in exceedingly small amount.

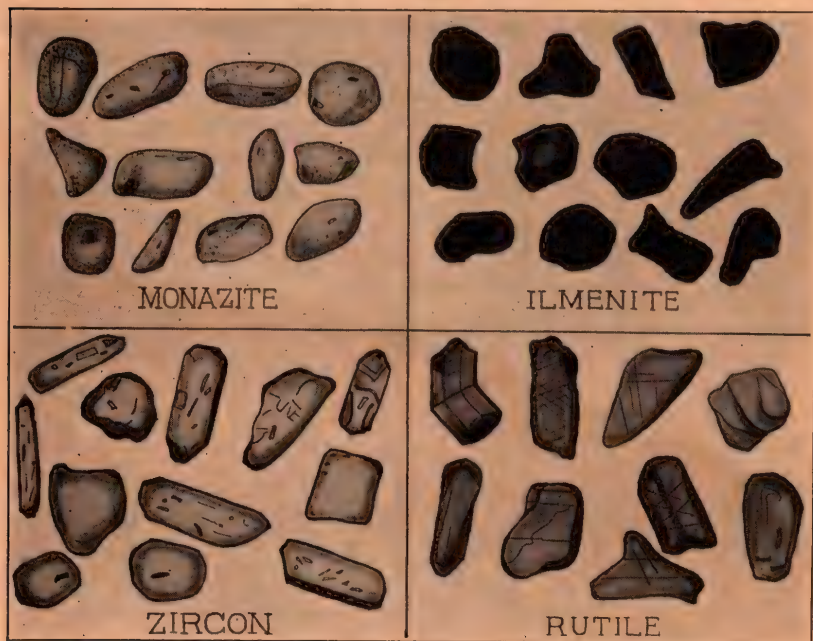
For convenience of reference the properties of the common minerals in Florida beach sands are summarized in table 7. The specific gravity, and the magnetic and electrical properties are especially important because all three of these are involved in the process of separation. The shape of the grains (Figure 30) depends partly upon the way in which the mineral has originally crystallized, and partly upon its hardness, since the softer grains are naturally more rounded than the harder ones.

TABLE 7
PROPERTIES OF SOME MINERALS IN FLORIDA BEACH SAND

<i>Name</i>	<i>Chemical Composition</i>	<i>Sp. Gr.</i>	<i>Hardness</i>	<i>Color</i>	<i>Luster</i>	<i>Magnetic Properties</i>	<i>Electrical Conductivity</i>
Quartz.....	SiO ₂	2.65.....	7.....	White.....	Vitreous....	Non-magnetic..	Bad
Ilmenite....	FeTiO ₃	4.4.....	5½.....	Black.....	Metallic.....	Moderately magnetic....	Good
Zircon.....	ZrSiO ₄	4.70.....	7½.....	White.....	Adamantine.	Non-magnetic..	Bad
Rutile.....	TiO ₂	4.24.....	6.....	Brown.....	Adamantine.	Non-magnetic..	Fairly good
Monazite....	About CePO ₄	5.1.....	5.....	Yellow.....	Resinous....	Weakly magnetic....	Bad
Epidote....	Ca ₂ Al ₂ (AlFe)OH(SiO ₄) ₃ .	3.4 to 3.5....	6 to 7.....	Greenish Yellow....	Vitreous....	Weakly magnetic....	Bad
Staurolite...	Fe(OH)Al ₅ (SiO ₆) ₂	3.7.....	7 to 7½.....	Brown.....	Vitreous....	Weakly magnetic....	Bad

Quartz.—Ordinary clear quartz is by far the most abundant mineral in the beach sand as a whole and generally predominates in the parts selected for mining. The grain is very fine, practically all being smaller than 0.4 mm. (0.016 inch), while a few of the smallest grains are about 0.1 mm. (0.004 inch) or about the same as the zircon and ilmenite. The grains show little rounding, but under the binocular microscope it can be seen that many of the sharpest corners have been worn off. Feldspar is present in small amount. There is about one grain of it to every fifty to one hundred grains of quartz. It was not listed separately from the quartz in the estimates of mineral composition.

Ilmenite.—In the heavy concentrates of the Florida beaches this is nearly always the most abundant mineral. It is black with brilliant metallic luster and is distinguished from rutile by being perfectly opaque and from the darker opaque varieties of collophane by the luster, the collophane being dull or waxy rather than metallic. The ilmenite grains generally show a moderate degree of rounding and are approximately equidi-



Drawn by F. C. Gibbons, Jr.

FIG. 30. Grains of monazite, ilmenite, zircon and rutile, from sand at Mineral City, St. Johns County. Magnification about 100 diameters.

mensional—that is, there is little difference between the length, breadth, and thickness. The usual size of grain in the vicinity of Mineral City is 0.10 mm. (.004 inch). A very few of the grains are about twice this size. Crystal faces are occasionally seen but nearly perfect crystals are rare if present at all.

Zircon.—This is almost universally present in quartz sand, but the size of the grains and the proportion of them is so small that it can rarely be seen without using a microscope or without concentrating the mineral in some way, or both. However, on some of the beaches where natural concentration of the heavy minerals is going on, light colored streaks of zircon may be seen among the darker rutile and ilmenite. The zircon can then be distinguished from quartz by its brilliant luster and smooth crystal faces. The zircon separated from the sand at Mineral City is in grains usually about 0.1 mm. in diameter, but varying considerably in size and shape. Each of the grains is a single crystal; many of them show the crystal faces to a high degree of perfection while others appear worn or broken. There are a few prismatic crystals as much as four or five times as long as wide, but crystals only slightly elongated are far more abundant. Practically all of the zircon on the Atlantic coastal beach from Mineral City to St. Simons Island, Georgia, is of the colorless variety, rarely showing zonal structures. Pale purple or lavender grains of zircon are present, but are very rare.

Rutile.—This generally is in grains a little larger than the ilmenite and zircon and showing a distinct tendency to elongation in the direction of the prism, although good crystals are rare. The usual size is about 0.15 by 0.20 mm. (0.006 by 0.008 inch). The general color of the separated rutile is a dark brown but as viewed under the microscope the different grains vary in color from light yellow and greenish yellow to dark reddish and dark brown, and some are almost opaque.

Monazite.—This is in grains of pale greenish yellow color usually about 0.10 mm. (.004 inch) in diameter but averaging a little smaller than the zircon. The grains of monazite are fairly well rounded—much more so than the quartz, rutile, zircon or ilmenite. No crystal faces can be seen, not because monazite does not form good crystals but because it is softer than the other minerals and therefore is worn more. Under the microscope most of the monazite can be distinguished from epidote by the larger size and ragged or angular appearance of the grains of the latter mineral. Monazite is enough heavier than the other minerals so that it can be separated in a nearly pure state. Unfortunately the amount of monazite in the sand is too small and the thorium content too low to make this mineral worth saving.

Staurolite, a silicate of iron and aluminum, is one of the most abundant minerals in the heavy concentrates at all of the localities. It is somewhat magnetic and it is therefore difficult to get the ilmenite completely separated from it. Staurolite is brown in color and in small grains may require microscopic examination to distinguish it from rutile, but the luster is not so bright. Staurolite in the form of sand has no commercial value.

Epidote.—This is a silicate of calcium, iron, and aluminum, and is present in a little larger amount than staurolite in the sand at Mineral City. The grains of epidote have a greenish yellow color similar to that of monazite but are larger and less rounded. Besides common epidote there is some *zoisite*, a closely related mineral. Epidote also is of no value, but on account of its magnetic properties and moderately high specific gravity it is difficult to separate all of the ilmenite from it.

Collophane.—This amorphous calcium phosphate mineral, which makes up the greater part of the Florida phosphate rock, occurs very sparingly in the beach sand at Mineral City. There is more of it in the tailings from the wet mill than there is in any of the other products of the milling operations. At Venice, on the southwest coast of Florida, collophane is about as abundant as quartz in some of the beach sand.

Other Minerals.—The numerous other minerals are of no great importance either in themselves or as affecting the problem of separating the useful minerals present in the sand. Their main interest is in connection with a study of the *origin* of the deposits, discussed in a later section.

QUANTITATIVE DETERMINATION OF MINERAL CONTENT.

On several specimens quantitative determinations of the mineral content were made by counting grains, and the resultant expression of the mineral composition (table 8) is in per cent by *number of grains*. On account of the difference in the average grain size and specific gravity of the different minerals this is not the same as per cent by weight. Such analyses have been made on fourteen specimens of heavy concentrates, from eleven localities. It should be emphasized that these are in most cases from thin layers of heavy concentrates associated with much larger amounts of sand consisting mostly of quartz, and that there are no deposits of workable size with so little quartz. Since the percentage of quartz is more or less accidental, and varies greatly in different specimens from the same locality, the relative proportions of the other minerals can be seen much more clearly by deducting the quartz and computing the other minerals to 100 per cent, thus obtaining the results shown in table 9 and Figure 31.

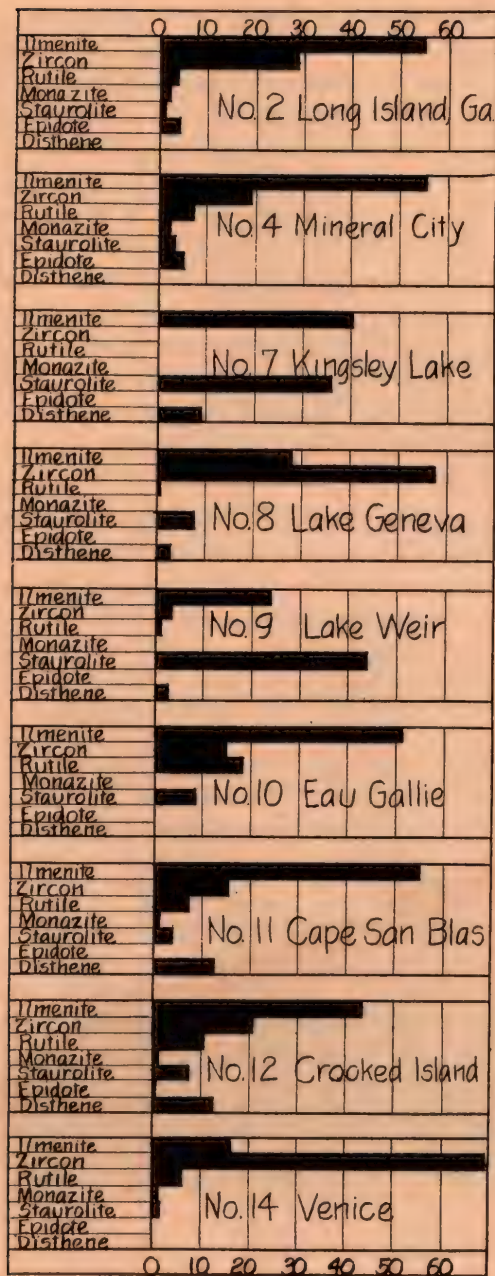


FIG. 31. Percentages by number of grains of principal heavy minerals in natural heavy concentrates from Florida and Georgia. Heavy minerals computed to 100 per cent after deducting quartz and feldspar.

The general similarity of the first four analyses, all of sands from the ocean beach of the east coast, is then very readily seen. The minerals are the same, and their relative proportions do not differ greatly. There is some suggestion of a decrease in the amount of zircon relative to ilmenite to the southward, but the number of localities represented by analyses is not great enough to prove this.

The three heavy concentrates from the lake beaches show some points of similarity; namely the absence or great scarcity of rutile, epidote, monazite, and hornblende, and the abundance of staurolite, disthene and sillimanite. No reason is apparent for the much higher zircon content of the Lake Geneva concentrate. Longer weathering may well account for the smaller number of minerals in these heavy concentrates from the interior of the peninsula, as compared with those on the east coast.

MINING AND MILLING OPERATIONS OF BUCKMAN AND PRITCHARD, INC.

Since the heavy concentrates occur either on the surface of the beach or under a very small overburden of loose sand, the methods of excavation are simple. The sand is loaded into trucks for transportation to the mill. For a part of the beach a narrow-gauge tramway was also used. An attempt to mine the ilmenite by dredging was unsuccessful because sufficiently rich concentrates did not extend to below water level.

The mill of Buckman and Pritchard, Inc., (Figure 32) at Mineral City



FIG. 32. Mill of Buckman and Pritchard, Inc., at Mineral City, St. Johns County.

was first built for the recovery of ilmenite only, but changes and additions have been made to adapt it to the recovery of rutile and zircon also, from the beach sand as well as from the tailings from the earlier operations for ilmenite.

The beach sand as worked contains about 20 per cent of "mineral", that is, of minerals other than quartz, feldspar, and shell. To recover the ilmenite, rutile and zircon from this and to separate them from each other is a very complicated process. The general outline of it is shown by the flow sheet (Figure 33). As the first step in the process the most of the quartz is eliminated in the wet mill, which consists of 18 Deister Overstrom tables, to which the sand is fed, mixed with water, from an overhead trough. A recovery of about 75 per cent is effected by the wet mill, and the concentrates, according to information furnished by Mr. W. M. Phillips, the works manager, have a composition as follows:

Ilmenite	55 per cent.
Zircon	20 per cent.
Rutile	6 per cent.
Monazite	2 per cent.
Greenspar	14 per cent.
Quartz	3 per cent.

The "greenspar" includes various silicate minerals, of which the principal ones are staurolite and epidote. A microscopic analysis of a single sample of the wet mill concentrates gave the results shown in table 8. This is probably higher in rutile and zircon, and lower in ilmenite and silicate minerals than the average. The percentage figures for a natural heavy concentrate from the beach near Mineral City (No. 4, table 9) after deducting the quartz, agree closely with these given by Mr. Phillips for the wet mill concentrate.

After drying, the product of the first concentration goes to the ilmenite magnets and ilmenite "statics." The ilmenite is the most strongly magnetic of the minerals present, and this makes it possible to pull it out by rather weak electro-magnets, while the fact that it is the best conductor of electricity makes it possible to separate it also by the "statics," as the Huff patent electro-static machines are called for short. The heads from the ilmenite statics and magnets are principally ilmenite; the magnet middlings, or material pulled out by the stronger magnets contain the greater

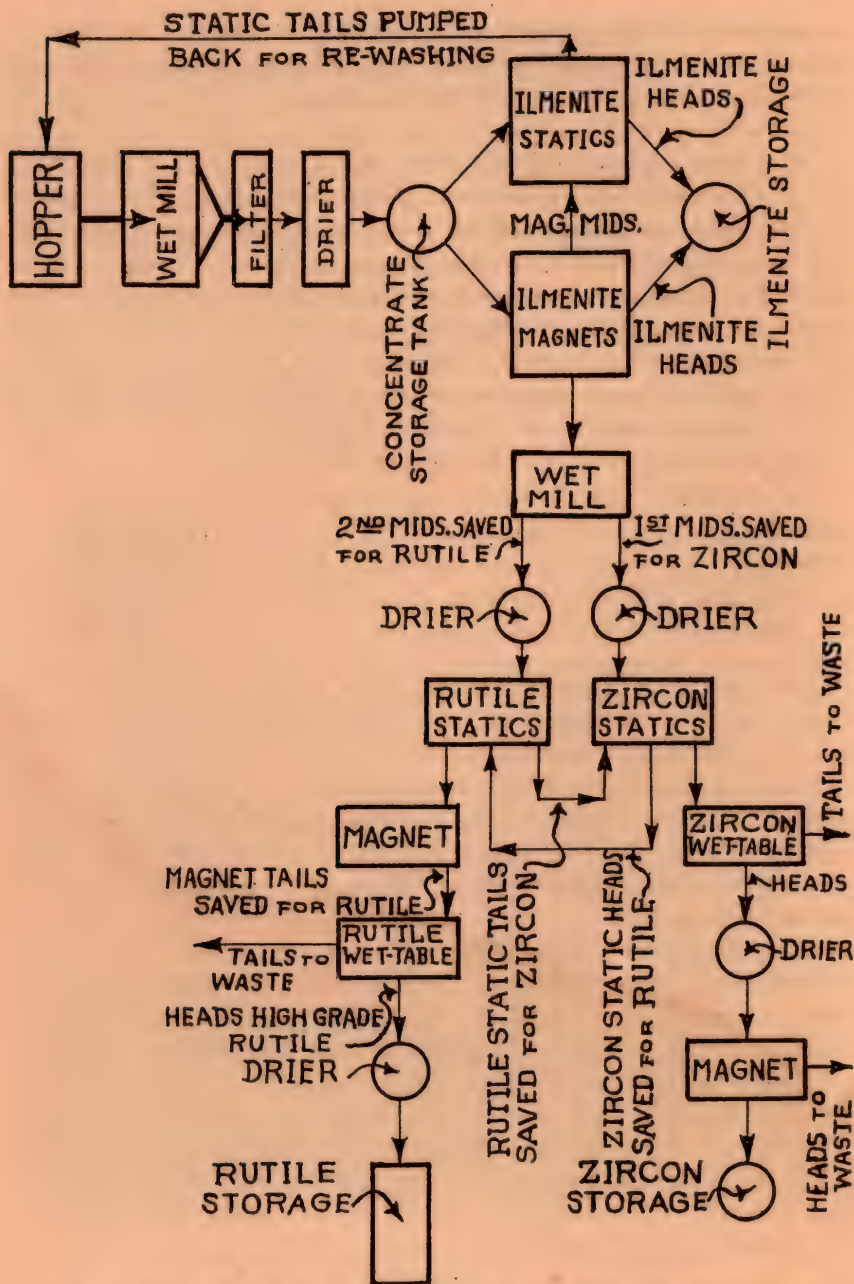


FIG. 33. Flow sheet of mill of Buckman and Pritchard, Inc., Mineral City, St. Johns County, showing operation on beach sand.

part of the iron bearing silicates and monazite, with some ilmenite which is recovered by the statics before discarding the rest as waste. The magnet tails consist principally of rutile and zircon.

A wet table eliminates from the rutile and zircon some still remaining monazite, quartz and silicate minerals. The separation of the rutile from the zircon is effected entirely by the electro-static machines, the action of which depends on the fact that rutile is a better conductor of electricity than zircon, and is therefore attracted more to an electrically charged body. Elimination of small amounts of other minerals still remaining in both the rutile and zircon is necessary in order to obtain a product of the desired purity. Magnets take out the ilmenite and wet tables separate the quartz and silicates. The separated ilmenite and zircon are shipped in tank cars, and the rutile in bags.

During the earlier mining operations when the ilmenite only was sought heaps of tailings accumulated from which most of the quartz had been separated by the wet mill and most of the ilmenite by the magnets; these tailings are now being worked over for the recovery of the zircon and rutile, as well as the small amount of ilmenite still remaining.

Figure 34 is the flow sheet for operation on tailings. Because of the rather small amount of quartz present in the feed the wet mill does not have to be run continuously to keep up with the rest of the mill. After drying, rather weak magnets take out part of the ilmenite together with part of the monazite and iron bearing silicates, but the ilmenite is far less pure than that produced at the same stage when operating on beach sand. Still stronger magnets take out most of the remaining ilmenite, monazite and iron bearing silicates; the minerals, other than ilmenite, in this second magnetic portion or middlings, are known collectively as "greenspar." These middlings from the magnets are treated on a wet table which produces monazite heads, ilmenite middlings and greenspar tails.

The tailings from the strongest magnets contain the zircon and rutile and are saved for their separation, which is effected by means of the Huff patent electro-static machines as when working on the beach sand, while the further purification of the rutile and zircon involves the steps shown on the flow sheet and is practically the same as has already been outlined. The principal difference between the flow sheet when working on the crude beach sand, and when working on the tailings, is that in the latter case electro-static machines are not used at all for the removal of ilmenite but only for the separation of rutile and zircon.

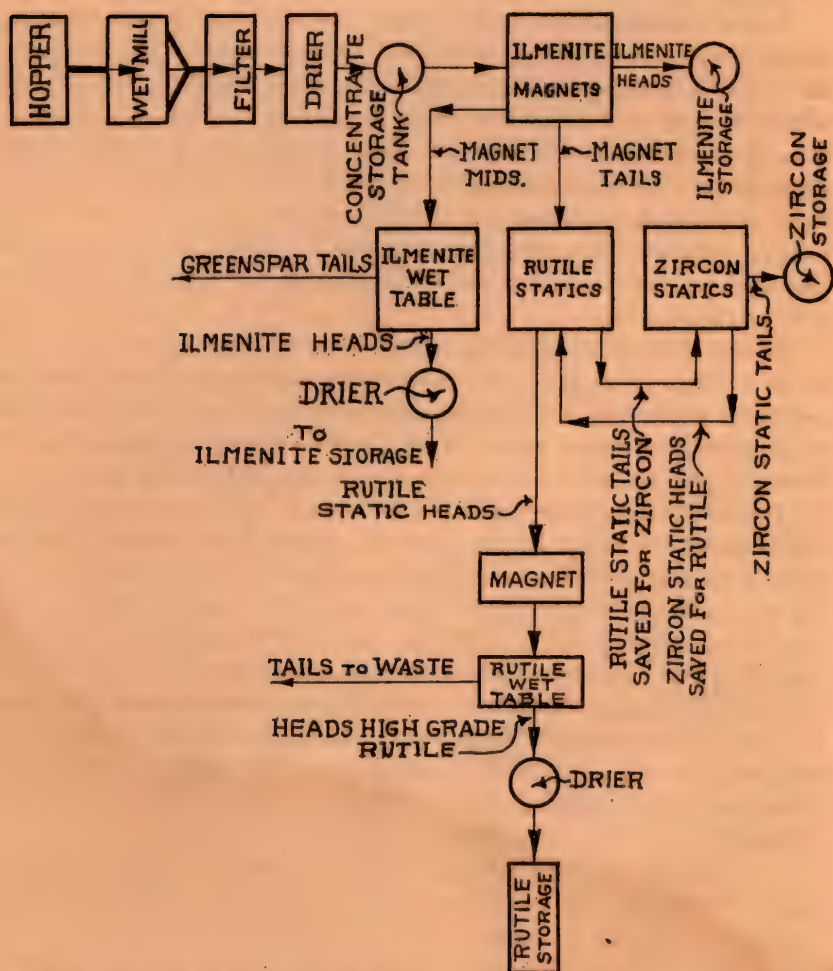


FIG. 34. Flow sheet of mill of Buckman and Pritchard, Inc., Mineral City, St. Johns County, showing operation on tailings.

OTHER OCCURRENCES IN FLORIDA AND GEORGIA

In the following brief descriptions of other occurrences of ilmenitic concentrates in Florida and Georgia no attempt has been made to include every locality at which such concentrates occur. Some slight concentrations of heavy minerals may be found on most of the quartz sand beaches and heavy concentrates even occur in a few places where there is a large amount of shell as well as quartz in the sand. The mineral composition of the heavy concentrates from most of these localities is shown in table 8, page 144, the percentage figures referring in every case to number of grains of the different minerals, and not to the weight.

AMELIA ISLAND, FLORIDA.

In the beach and dune sand of Amelia Island in the extreme northeastern corner of the State, ilmenite is everywhere present in small amount and thin streaks of dark, heavy concentrates are common but the amount is far from sufficient to have any practical value. Analysis No. 3, tables 8 and 9, shows essentially the same heavy minerals as in the sand from Mineral City. The specimen analyzed was taken three miles south of St. Marys River jetty and represents a cut to a three-inch depth, on the upper part of the beach, 20 feet in front of the dunes. Several alternating thin layers of light and dark sand were included.

ST. SIMONS ISLAND, GEORGIA.

At the south end of the island near the light house and post office there are some heavy concentrates on the upper part of the beach. A sample representing a five-inch depth has the mineral composition shown in column 1, tables 8 and 9. A chemical analysis published by the Georgia Geological Survey,¹ without mention of the analyst's name, gave the results quoted below:

Lime (CaO)	0.00
Magnesia (MgO)	0.00
Alumina (Al ₂ O ₃)	0.00
Ferric oxide (Fe ₂ O ₃)	7.84
Ferrous oxide (FeO)	11.29
Manganous oxide (MnO)	1.89
Titanium dioxide (TiO ₂)	34.40
Phosphorus pentoxide (P ₂ O ₅)	0.18
Silica (SiO ₂)	43.12
Zirconium oxide (ZrO)	0.12
Thorium oxide (ThO ₂)	0.28
Cerium oxide (CeO ₂)	0.53
Total	99.65

¹Teas, L. P. Preliminary Report on the Sand and Gravel Deposits of Georgia. Georgia Geological Survey Bulletin No. 37, p. 376.

While the sand collected and examined microscopically by the writer may differ from that analyzed chemically, especially in the amount of quartz, the amount of zirconium oxide shown by the chemical analysis must be far too low.

On the beach of Long Island also, which is outside of the northern part of St. Simon Island and separated from it by a marsh, there are some black sand concentrates. The greatest amount is near the crest of the beach ridge, a little above high tide level on the gently sloping beach. A specimen scraped up from a thin layer on the surface about one mile from the north end of Long Island, has the mineral composition shown by No. 2, in tables 8 and 9, which is very similar to that of the Mineral City black sand.

SAPELO ISLAND, GEORGIA.

The occurrence of black sand on Sapelo Island is reported by the Georgia Geological Survey¹ and a chemical analysis is given.

EAU GALLIE, FLORIDA.

On the west side of Indian River $1\frac{1}{2}$ miles north of the main part of the town of Eau Gallie the beach has heavy mineral concentrates rich in ilmenite and rutile (Figure 35). Much of the way bluffs of coquina rise directly from the water, so that the beach is not continuous for great dis-



FIG. 35. Ilmenite sand and coquina outcrop on west side of Indian River, $1\frac{1}{2}$ miles south of Eau Gallie, Brevard County.

¹Bulletin 37, p. 377.

tances, and it is everywhere narrow. Similar narrow beaches with heavy concentrates occur at several other places on Indian River. The black sand from Eau Gallie is much coarser than that from Mineral City and that may be one of the reasons for the large difference in the amounts of rutile and staurolite. (No. 10, tables 8 and 9).

VENICE, FLORIDA.

On the Gulf beach at Venice, for a distance of 2 miles or more south of Casey's Pass, black sand appears in considerable amount. The principal concentration is from the top of the beach ridge down to a little below high tide line, and therefore differs in its position from that at Mineral City. The black material shows directly on the surface in the strip which ordinary waves are working over in calm weather. (Figure 36). There is a layer from one to four inches thick with little quartz, and many thinner layers of darker minerals alternating with quartz sand and shell. A large part of the dark mineral on this beach is the calcium phosphate mineral collophane in well-rounded grains, rather than rutile and ilmenite. There is more of it with the medium and coarse sand than there is in the fine sand. In fact the coarser material of the beach is mostly shell and phosphate, with little mixture of the heavy minerals. On some parts of the beach the sorting out of the zircon from most of the other heavy minerals, as well as from



FIG. 36. Beach at Venice, Sarasota County. Shows black sand which contains a large amount of calcium phosphate grains. Hardpan is exposed by wave erosion on the back part of the beach.

TABLE 8
MINERALOGICAL ANALYSES OF HEAVY CONCENTRATE SANDS FROM FLORIDA AND GEORGIA

*Specimen Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total Grains Counted.....	5,429	2,004	1,121	1,586	3,220	1,262	937	1,038	433	1,586	877	1,855	1,933	3,127
Per cent by number of grains.														
Quartz and Feldspar	7.1	6.9	52.9	11.9	1.5	5.0	9.6	30.2	40.2	2.3	68.2	12.4	41.5	1.1
Ilmenite	49.4	51.1	25.6	49.6	45.9	31.2	36.3	19.8	20.3	50.4	17.7	38.0	6.8	16.5
Zircon	28.6	27.3	11.2	17.2	32.0	2.1	0.3	40.2	2.1	14.7	5.0	17.9	6.6	68.6
Rutile	5.2	3.8	2.0	6.6	9.7	3.3	.....	0.6	0.7	18.2	2.4	9.2	1.0	6.6
Monazite	4.2	2.2	1.9	2.1	3.6	4.7	.....	.....	.....	0.1	0.5	1.1	0.05	1.5
Staurolite	1.3	1.4	1.3	3.0	2.2	18.1	32.3	5.4	25.6	8.9	1.3	6.8	1.9	1.7
Epidote	2.0	4.2	1.5	4.8	2.8	26.8	.....	.....	.....	0.1	0.3	.....	0.6	0.06
Garnet	0.9	1.0	0.5	1.2	0.9	1.6	.....	.....	.....	5.0	x	0.05	0.9	1.6
Disthene	0.3	0.2	0.4	0.6	0.2	0.2	8.4	2.1	1.6	x	3.7	10.9	1.0	0.6
Sillimanite	0.3	0.4	0.7	0.9	0.2	0.9	5.2	0.7	4.4	0.06	0.2	0.4	0.7	0.03
Tourmaline	0.04	0.1	0.4	0.3	0.1	1.3	3.1	0.7	4.2	0.2	0.6	1.7	0.6	0.03
Hornblende	0.1	0.4	0.3	0.2	0.2	1.4	.....	.....	.....	0.2	.....	.....	0.05	.....
Leucoxene	0.4	0.5	0.4	0.6	0.5	2.8	4.6	0.3	0.9	0.1	0.1	1.3	0.1	0.2
Titanite .....	.....	0.05	.....	0.1	0.1	0.2	.....	.....	.....	.....	.....	.....	x	0.2
Spinel	0.08	x	x	x	0.1	0.2	x	0.1	x	0.06	0.1	0.5	x	0.1
Corundum .....	.....	.....	.....	0.1	x	.....	x	x	x	.....	.....	.....	x	.....
Andalusite .....	.....	.....	.....	.....	.....	.....	x	x	x	.....	.....	.....	0.1	.....
Collophane	0.2	0.4	0.6	0.9	0.2	0.3	.....	.....	.....	.....	.....	.....	36.0	1.8
Anatase	x	.....	.....	x	x	.....	.....	.....	.....	.....	.....	.....	.....	.....
Shell (Calcite) .....	.....	x	x	x	.....	.....	.....	.....	.....	.....	x	0.1	2.3	x
Total	99.9	100.2	100.1	100.1	100.2	100.1	99.8	100.1	100.0	100.1	99.9	99.9	100.2	100.4

x—Indicates presence of mineral in amount so small that it did not appear among the grains counted.

*—Location of specimen.

1. Natural heavy concentrate, St. Simons Island, near Brunswick, Georgia.
2. Natural heavy concentrate, Long Island, near Brunswick, Georgia.
3. Natural heavy concentrate, Amelia Island, Nassau County, Florida.
4. Natural heavy concentrate, 3 miles north of Mineral City, Florida.
5. Wet mill concentrate, Buckman and Pritchard, Inc.
6. Greenspar tailings, Buckman and Pritchard, Inc.
7. Natural heavy concentrate, north side Kingsley Lake, Clay County, Florida.

8. Natural heavy concentrate, east side Lake Geneva, Clay county, Florida.
9. Natural heavy concentrate, north side Lake Weir, Marion county, Florida.
10. Natural heavy concentrate, Eau Gallie, Florida.
11. Natural heavy concentrate, Cape San Blas, Gulf county, Florida.
12. Natural heavy concentrate, Crooked Island, Bay county, Florida.
13. Natural heavy concentrate, Venice, Sarasota county, Florida.
14. Natural heavy concentrate, Venice, Sarasota county, Florida.

the quartz and phosphate, could be observed. The zircon is the heaviest of the minerals which is present in any considerable amount, and the waves therefore leave it highest on the beach. This very rich zircon sand, scraped up from a layer only a small fraction of an inch in thickness, has the mineral composition shown in tables 8 and 9, No. 14, while the more common type of heavy concentrates at Venice is represented by analysis No. 13.

CAPE SAN BLAS, GULF COUNTY, FLORIDA.

On the peninsula between Cape San Blas and Point St. Joseph thin layers of heavy concentrates extend for some miles along the upper part of the Gulf beach, near the front of the dunes. This part of the beach is reached only by storm waves or extremely high tides, and there are no heavy concentrates in the strip which the waves are working over in calm weather. The deposit is of a type similar to that at Mineral City, but does not appear wide enough and thick enough to be of commercial importance under present conditions. Analysis No. 11, tables 8 and 9, shows the composition of a specimen scraped up from a thin layer on the surface of the beach, about one mile northwest of the southern extremity of the Cape.

CROOKED ISLAND, BAY COUNTY, FLORIDA.

On the shoreward side of Crooked Island, along St. Andrews Sound, there are some small deposits of heavy concentrates from about low tide to a little above high tide. The concentration is evidently accomplished by the gentle lapping of small waves on the sand, since the locality is sheltered fairly well from storms.

On the outer beach of Crooked Island, about opposite the end of the road from Auburn to St. Andrews Sound, there are thin layers of heavy concentrates, alternating with light colored quartz sand. The heavy and dark minerals are most abundant on the upper part of the beach near the foot of the dunes. The mineral composition of one of the darkest layers, ($\frac{1}{4}$ -inch thick) is shown by analysis No. 12, tables 8 and 9. It is seen to be especially rich in staurolite and disthene, two minerals commonly occurring together. While only a small part of the Crooked Island beach was examined, no indications were seen of any deposit large enough to be workable.

TABLE 9
MINERALOGICAL ANALYSES OF HEAVY CONCENTRATE SANDS FROM FLORIDA AND GEORGIA
Other minerals computed to 100 per cent after deducting quartz and feldspar.

*Specimen number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total Grains Counted.....	5,046	1,865	527	1,400	3,174	1,199	847	724	259	1,550	280	1,625	1,129	3,092
Per cent by number of grains.														
Ilmenite	53.2	55.0	54.6	56.2	46.5	33.0	40.4	28.0	34.0	51.5	55.4	43.4	11.6	16.7
Zircon	30.8	29.3	24.1	19.4	32.6	2.2	0.4	57.6	3.5	15.0	15.7	20.5	11.2	69.4
Rutile	5.8	4.1	4.4	7.5	9.9	3.2	.....	0.8	1.2	18.7	7.5	10.5	1.7	6.7
Monazite	4.5	2.4	4.0	2.4	3.6	4.9	.....	.....	.....	0.1	1.4	1.2	0.1	1.5
Staurolite	1.4	1.6	2.8	3.4	2.2	19.1	35.8	7.7	42.8	9.1	3.9	7.8	3.2	1.7
Epidote	2.1	4.6	3.2	5.4	2.8	28.2	.....	.....	.....	0.1	1.1	.....	1.0	0.06
Garnet	1.0	1.0	1.1	1.3	0.9	1.7	.....	.....	.....	5.1	x	0.06	1.5	1.6
Disthene	0.3	0.2	0.8	0.6	0.2	0.2	9.3	3.0	2.6	x	11.5	12.5	1.7	0.6
Sillimanite	0.3	0.4	1.5	1.1	0.2	0.9	5.8	1.0	7.3	0.06	0.6	0.4	1.2	0.03
Tourmaline	0.04	0.1	0.8	0.3	0.1	1.4	3.4	1.0	6.9	0.2	1.8	2.0	1.0	0.03
Hornblende	0.1	0.5	0.6	0.2	0.2	1.5	.....	.....	.....	.....	0.7	.....	0.1	.....
Leucoxene	0.5	0.6	1.0	0.6	0.5	3.0	5.2	0.4	1.5	0.1	0.4	1.5	0.2	0.2
Titanite .....	.....	0.05	.....	0.1	0.1	0.2	.....	.....	.....	.....	.....	.....	x	0.2
Spinel	0.08	x	x	x	0.1	0.2	x	0.1	x	0.06	0.4	0.6	x	0.1
Corundum .....	.....	.....	.....	0.1	x	.....	x	x	x	.....	.....	.....	x	.....
Andalusite .....	.....	.....	.....	.....	.....	.....	x	x	x	.....	.....	.....	0.2	.....
Collophane	0.3	0.4	1.3	1.1	0.2	0.3	.....	.....	.....	.....	.....	.....	61.6	1.8
Anatase	x	.....	.....	x	x	.....	.....	.....	.....	.....	.....	.....	.....	.....
Shell (Calcite) .....	.....	x	x	x	.....	.....	.....	.....	.....	.....	.....	0.1	4.0	x
Total	100.2	99.4	100.2	99.7	100.1	100.0	100.3	99.6	99.8	100.0	100.4	100.0	100.3	100.4

x—Indicates presence of mineral in amount so small that it did not appear among the grains counted.

*For location of specimen see footnote of Table 8.

INLET BEACH, WALTON COUNTY AND BAY COUNTY, FLORIDA.

On the Gulf Beach, in the vicinity of Phillips Inlet, for a distance of two miles to the east and five miles to the west of the inlet, or as far as it was examined, the beach sand as a whole is everywhere dazzlingly white, but darker minerals are frequently in evidence. These form a thin coating over the surface of parts of the beach where the lighter minerals have been washed away by the waves or blown by the wind. On the back part of the beach there are alternating layers of heavy concentrates of dark color and of white quartz sand. Microscopic examination shows that the mineral composition of the dark layers is similar to that shown by the analyses of heavy concentrates from Crooked Island and Cape San Blas. However there seems to be relatively more of staurolite and disthene and less of ilmenite, zircon and rutile than at the two other localities.

SANTA ROSA ISLAND, FLORIDA.

On the north side of Santa Rosa Island, opposite Camp Walton, there are thin narrow strips of heavy minerals along the shore. The composition of the heavy concentrates is probably similar to that on Crooked Island.

LAKE BEACHES.

Heavy mineral concentrates occur in small amount on many lake beaches including Barnes' Beach on the north side of Lake Weir, Marion County; the east side of Lake Geneva, Clay County; and the Kingsley Lake Beach at Strickland's resort, Clay County. The mineral composition of these is shown by analyses 9, 8 and 7 respectively in tables 8 and 9. Although the small variety of minerals would favor the recovery of ilmenite the extent of the deposits is not sufficient to justify exploitation.

ORIGIN OF DEPOSITS.

A number of steps are involved in discussing the origin of the black sand deposits of Mineral City, but if some of the details may not yet be thoroughly understood, the general outline of the processes by which they were formed is much more obvious than in the case of most ore deposits. The minerals of these heavy concentrates, regarded by some as rare, are among those most widely distributed as constituents of sands and other rocks. Zircon is rarely absent from ordinary quartz sand, while ilmenite and rutile are nearly as common. Another mineral which is present in about the same order of abundance and the same frequency of occurrence in sands is tourmaline, but no use for this has yet been found when in the form of small grains, and moreover, its specific gravity is not high enough so that there is so much tendency for it to be concentrated by natural processes as are the other minerals with which we are here concerned. Of 40 British sedimentary formations for which Milner¹ lists the principal minerals present, the number of formations in which each of these minerals was found was zircon 39, tourmaline 37, rutile 34, and ilmenite 33. Next after quartz these are the four most widely distributed minerals in sediments. *Titanium* is also one of the most common chemical elements in the earth with respect to actual *quantity* present, as well as frequency of occurrence. According to Clarke² the average amount of it present in the rocks near enough to the surface of the earth so that they are fairly well known by chemical analysis, is 1.03 per cent, expressed as TiO_2 .

The rocks of the Piedmont Region of Georgia, and perhaps to some extent of North and South Carolina as well, are the ultimate source of the heavy minerals in the beach sands of the Florida east coast and of the quartz also. The only grains in the sand which are actually formed in the Coastal Plain are the shell fragments and the collophane. By their disintegration, such rocks as schists, gneisses and granites yield all of the other minerals found in these sands, but most of these minerals are not known to be commonly formed in sedimentary rocks. The *relative proportions* of the various minerals, both heavy and light, are very much different in the sand from what they are in the bed rocks from which it is derived, but that is the result of the long series of intervening processes.

¹Milner, H. B., *An Introduction to Sedimentary Petrography*, 1922, pp. 118-119.

²Clark, F. W., *The Data of Geochemistry*, U. S. G. S. Bull. 770, p. 34.

In the first place, the action of the atmosphere, in disintegrating a solid rock and converting it into an incoherent soil, destroys some of the minerals much more completely than it does others. The feldspar, for example, is mostly converted into fine clayey material which is more easily carried by water than are sand grains, and therefore comes to rest at quite a different place from the sand. Likewise some of the common darker colored and heavy minerals including hornblende, magnetite and others, are more easily destroyed by weathering than are the zircon, ilmenite and rutile.

The products of decay of the rocks of the Piedmont region are carried to the sea by rivers, of which the one discharging into the Atlantic nearest to Florida is the Altamaha, whose mouth is distant about eighty miles from the part of the beach where the most important of the deposits under discussion occur. During the movement down the river the softer minerals are continually being worn away faster than the harder ones. Usually the softer minerals are more liable to chemical alteration than the hard ones and this will tend to make them disappear more rapidly. From the beginning of the formation of the sand quartz is the most abundant mineral but with increasing distance from the source the percentage of this continually increases.

After the sand is discharged into the sea by rivers the movement of it is continued by the combined action of various currents, including those due to tides and to wind waves. That the net result of these currents is a southward movement is proved by the southward shifting of inlets on the east coast.

The partial or complete elimination of a number of minerals is an important part of the steps leading up to the formation of the final concentrate rich in ilmenite and zircon. Two minerals which are very often present in large amount in natural heavy concentrates of beach sand are magnetite and garnet. In this instance the magnetite has practically all been removed by weathering and the garnet goes mostly into sand coarser than that with which the heavy concentrates at Mineral City occur. If much magnetite were present it would have to be removed by a very weak magnet before taking out the ilmenite; while garnet is less strongly magnetic than ilmenite and could be separated from it by either magnetic or electro-static means but its presence in large amount might complicate the process. Most of the mica is also naturally separated from the rest of the sand, not so much because of its chemical or mechanical destruction, although these are effective to some extent, but mostly because it occurs in such flat light flakes that they are carried away by currents that will not move sand grains of quartz.

Some of the grains have not come by any direct path as indicated above, but have come by devious ways, indirectly from their source in the Piedmont, and have been delayed in various sediments of the Georgia Coastal Plain for perhaps millions of years, before they were picked up by the rivers and started again on their way to the Florida beaches. Moreover, in many parts of the Florida coast the waves are eroding sands and other sediments which were transported from the north long ago and have been a part of the Coastal Plain deposits of this State. In the northeastern part of Florida the waves are acting on material which is principally of Recent age with perhaps some Pleistocene but none definitely older than that, and all the indications are that the Pleistocene sands were carried south under conditions not greatly different from those prevailing today.

The formation of the "black sand" by the concentration of grains of ilmenite, rutile, zircon and other heavy minerals scattered sparingly through the beach sand, is in the case of the deposits of the Mineral City region, the result principally of wave action during time of storm. Ordinary waves could not be effective because they do not reach high enough. The action of wind in blowing sand from the upper part of the beach, when it is dry, over onto the back side of the dunes seems to leave thin layers or sprinklings of dark minerals on this part of the beach and on the outer part of the dunes, but is not competent to produce layers of heavy minerals two or three inches thick. Since the best part of the deposits near the mill have been worked out, some *re-concentration* of the heavy minerals remaining in this part of the beach, has been effected by storms.

At a number of other localities where the writer has made observations, including Eau Gallie on Indian River, Venice Beach, and many lake beaches, the maximum concentration of the heavy minerals is going on in the strip *ordinarily* worked over by waves rather than on the part of the beach reached only under extreme conditions. In such cases as this there is usually more of the heavy minerals at about the high tide line on the ocean beaches than there is elsewhere, and likewise at normal water level on the lake beaches. If a beach ridge is developed there is sometimes a notable amount of black sand on the front of it just below the crest.

It is quite obvious that with sand of about the same texture and with the same minerals present, the beaches everywhere are by no means equally favorable for the natural sorting out of heavy minerals in sufficient amounts to justify commercial exploitation. Conditions are most favorable where the coast is being eroded away and the least favorable where it is being built up rapidly by the bringing in of additional supplies of

sand. Where the sea is eroding the beach the sorting may not be going on much more effectively at any particular instant, but since the general tendency is for the heavy minerals to be left on the upper part of the beach and the light ones to be carried below the water with the waves the sorting is cumulative, and the beach as a whole may become gradually richer in heavy minerals. A few examples which agree with this hypothesis will not definitely establish it but they may make it seem more reasonable.

That the shore near Mineral City and for some miles to the north and south is being worn away is well proved by comparison of old surveys with recent ones, by the wave cut cliffs in the dunes, and by the destruction of trees growing on dunes by undermining by the waves. To the northward, Amelia Island and Little Talbot Island are both receiving additions of material on the seaward side. As proof of this we have the known changes in topography and also the treeless dune area on which the trees have not yet had time to grow. On neither of these stretches of beach were any heavy concentrates found, which would compare in width or thickness with the Mineral City deposits.

Then we have Venice Beach, where heavy concentrates are found in abundance and where there is undoubted evidence of erosion taking place, in the way of outcrops of sandy limestone and hardpan sand on the shore. (Figure 35). To the north of Venice on Treasure Island, across Casey's Pass, and eight miles to the south of Venice on Manasota Beach there are only the very thinnest streaks of dark minerals and at both of these localities the shore has been growing outward by the addition of shell and sand in recent years.

At many other places beside those near Mineral City can be found heavy concentrates with an equally large percentage of zircon, ilmenite and rutile, and perhaps other deposits may have equally great or greater width and thickness, but rarely, if anywhere in the southern United States is there such a long stretch of beach where conditions have been so uniformly favorable for concentration. The beach is straight, the composition of the beach itself and of the shore in back of it is about uniform, and the profile of the sea bottom perpendicular to the shore is fairly constant. Where the shore is more broken up by inlets and islands more variable conditions would be expected, so that the length of the heavy mineral deposits would be less and even if everywhere present on the beach they would not be so easily accessible.

RELATION OF ORIGIN TO DISTRIBUTION AND EXTENT.

From the explanation of the origin of these deposits which has just been given it will be understood that their formation is limited to beaches, of either the ocean or lakes. When black sand deposits containing ilmenite, zircon and rutile are found on the beach there is no assurance that the beds extend either back into the land or out under the ocean; in fact the contrary is nearly always true. While concentrates formed by wave action may be covered by wind blown sand and thus extend back a short distance under the dunes, and the sorting effect of the waves may be felt to a slight extent for a short distance out beyond the low tide line we may say in general that not only are the deposits limited to the beach but they are in any particular case limited to some definite part of the beach. From this fact, and from our observation that the most extensive concentrations are formed under conditions of *wave erosion*, it may be seen that the chance of large deposits of this type being preserved in *ancient formations* is very slight indeed; conditions would not at the same time be favorable for the continued concentration of the heavy minerals, and for the covering up and preservation of the heavy concentrates as formed. Moreover, no deposits of this type belonging to past geologic periods would have so little overburden as those of the present day beaches. In Japan¹ beach deposits of iron ore much more extensive than any of the Florida ilmenite deposits, have been worked for many years, and these are associated not with the shore line of the present day, but with one at an elevation of 800 feet above the sea, indicating that the land has risen or that the sea has sunk since their formation.

While the beach deposits of ilmenite and the other heavy minerals associated with it are of a temporary nature because they are likely to be swept away by the waves, yet the processes which formed them are still acting at the present day so they may be renewed to some extent in a short time. By either natural or artificial changes in the coast line conditions may be altered enough so that heavy concentrates will form where they did not before, or so that those already formed will be washed away or deeply covered.

¹Neill, James W., Making Iron from Beach Sands in Japan, Engineering and Mining Journal, Vol. 123, pp. 243-245, 1927.

USES OF ILMENITE, RUTILE AND ZIRCON.

Rutile and Ilmenite.—Since they are both compounds of titanium, rutile and ilmenite have uses which are to a certain extent similar, although rutile is more suitable for the preparation of the pure compounds of the metal because it contains much less iron. Finely divided titanium dioxide makes a very good white pigment, which is used in paints for both exterior and interior use. Titanium nitride is being used for electrodes in place of carbon. Various alloys of titanium are made for special purposes. These include titanium bronzes, titanium steels, and carbon-free iron titanium alloys. Titanium tetrachloride is a strongly fuming liquid which is used in warfare for such purposes as smoke screens, tracer bullets, and gas offense.

The following analyses of the ilmenite and rutile mechanically separated from the sand at Mineral City are published by permission of the Titanium Pigment Company, Inc., of St. Louis, Mo., in whose Laboratory they were made:

	Ilmenite.	Rutile.
TiO ₂	53.66%	90.80%
FeO	17.09	.....
Fe ₂ O ₃	18.68	2.91
SiO ₂	3.80	1.65
MnO	1.36	.....
Al ₂ O ₃	1.12	.....
ZrO ₂	0.94	.....
P ₂ O ₅	0.84	.....
CaO	0.72	.....
H ₂ O	0.70	.....
Total	98.91	94.36

Zircon.—Before being used the zircon as produced by the mill at Mineral City is further purified by chemical means to remove the rutile which is mixed with it. The heat-resisting properties of zircon make it especially suitable for refractories, and it is used in crucibles and for the lining of kilns, muffles and retorts. Zirconium dioxide is used in opaque white enamels to replace the corresponding tin compound. It is a nonconductor of electricity and is acid proof. Among other possible uses of zircon and zirconium compounds derived from it are special alloys, abrasives, optical glass, zirconium-nickel cutting tools, aeroplane motor spark plugs and electrical resistance units.

The following analysis of zircon mechanically separated from the sand at Mineral City is published by permission of the Titanium Pigment Company, Inc., of St. Louis, Mo., in whose laboratory it was made:

ZrO ₂	57.25%
SiO ₂	29.18
TiO ₂	8.80
Fe ₂ O ₃	0.60
Al ₂ O ₃	4.05
P ₂ O ₅	trace
<i>Total</i>	99.88%

Monazite is the principal source of thorium and the rare earth metals, including cerium and several others. Thorium oxide is used in gas mantles, and cerium in pyrophoric alloys for cigar lighters, and gas lighters. Since better supplies are obtained from foreign countries, the monazite in Florida has no commercial importance at present.

Greenspar.—This name has been applied to a waste product the composition of which is shown by analysis No. 6, tables 8 and 9. Some of it has been used for a special type of wall surfacing.

CONCLUSION.

A number of deposits which have not yet been worked, but of which some may possibly become of commercial importance, have been mentioned. The reconcentration of the heavy minerals remaining on the beach at localities where the best material has already been removed, and the formation of new deposits either by an unusual storm or by a general slow change in the coast taking place either naturally or as a result of harbor and channel improvement works, may somewhat prolong the life of the industry.

While the field work has not been sufficiently detailed to allow any quantitative estimates of sizes of deposits, from the information available it seems rather doubtful whether any of the other ilmenite sand deposits are as extensive as those near Mineral City. If there is sufficient demand for ilmenite, rutile and zircon perhaps some of the smaller deposits can eventually be worked. In case the amount of material at any one place does not justify the erection of a mill it might be possible to use a portable outfit for separating the heavy minerals from the quartz on the beach and transport the concentrates to the mill for the final separation of the different heavy minerals.

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